Cracked Rotors

A Survey on Static and Dynamic Behaviour Including Modelling and Diagnosis

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Foreword

A very rich, but also in some way confusing, literature about cracked rotors has appeared in the last 30 years and is still developing. Since the authors have been involved in analyses of experimental data from power plants, in studies, in laboratory tests, in development of models and in numerical analyses of cracked rotors for more than 20 years, they felt that time was ready to publish a book about cracked rotors that should contain the main achievements obtained.

The focus of this book was intended on practical aspects related to industrial machinery and to numerical analyses aimed to represent their behaviour, rather than on theoretical investigations.

Since the background of the authors is mainly rotor-dynamics, some contributions of other experts have been asked for to cover some areas that are not strictly related to this field.

The book is devoted to all engineers or technicians that are in some way involved in the design, in the condition monitoring, in the maintenance of rotating machinery or in the management of any plant in which rotating machineries are installed, especially to those who are responsible of the safety of the plant, as well as to researchers or students that are interested in the topic of developing cracks in rotating shafts.

Chapter 1 is dedicated to the general introduction and to the overview of development and propagation of cracks in rotating shafts.

The typical experimental behaviour of cracked rotating shaft is described in chapter 2, as it has been measured in industrial machines.

Chapter 3 introduces the possible testing techniques that can be employed for detecting a crack in rotating shafts.

Chapter 4 is dedicated to provide a deeper insight into the breathing mechanism of a crack and into its thermal sensitivity, as it results from a series of experimental laboratory tests.

The modelling of the stiffness variation due to the presence of cracks in shafts, as proposed by different researchers, the modelling of breathing mechanism and related stiffness variation and finally the calculation of the dynamical response of a full size cracked rotor is described in chapter 5.

Chapter 6 is dedicated to a comparison of calculated results to experimental results obtained using both a medium size test rig and a full size shaft-line of a turbo-generator and to the sensitivity analysis performed with the most suitable models: how the position of the crack, how its shape and how its depth influence the system response.

Chapter 7 describes some second order effects, like: i) the excitation of torsional and axial vibrations, ii) the effect of a slightly helicoidal development of cracks, as it can occur in case of huge torsion loads, compared to the more common transverse cracks and finally iii) the comparison between the results obtained with linear models and those obtained with the fully non-linear approach, showing what could be the effect of very deep cracks on very light shafts loaded with rather high unbalances. These last effects are shown using the model of the shaft of a small machine, supported by oil-film bearings, that is anyhow more representative than the usual very simple Jeffcott / de Laval rotor.

Chapter 8 is entirely dedicated to the diagnosis of cracks in rotating shafts, assuming that only the usual measurements in correspondence of the bearings are available to detect the presence of a crack, in a possible early stage of its development. It is shown that not only the crack can be detected, but also its position and depth can be identified, using a model based method.

Contents

Acronyms

1X: once per revolution harmonic component
2X: twice per revolution harmonic component
3X: three-times per revolution harmonic component
AC: alternate current
BWR: boiling water reactor
CCL: crack closure line
CETIM: Centre Technique des Industries Mécaniques
CF: certainty factor
DC: direct current
d.o.f.s: degrees of freedom
EDF: Électricité de France
EDM: electrical discharge machining
EE: environmental effects
EFIT: elasto-dynamic finite integration technique
ET: eddy current testing
FCP: false-call probability
FE: finite element
FEM: finite element model
FES: far end scan
FN: false negative response
HF: Human factors
HP: High pressure
ID: inner diameter
IP: Intermediate pressure
LEFM: Linear Elastic Fracture Mechanics
LP: Low pressure
MPI: magnetic particles
NDE: non-destructive evaluation
NDT: non-destructive testing
NES: near end scan
OD: outer diameter
PA: phased array
POD: probability of detection
POND: probability of non detection
POR: probability of recognition
PT: dye penetrant testing

PWR: pressurized water reactor
RCP: Reactor cooling pump
RHS: right hand side
ROC: relative operating characteristic
RRP: Reactor recirculation pump
RT: x-ray testing
SERR: strain energy release rate
SIF: stress intensity factor
TOFD: time of flight diffraction
UT: ultrasonic testing
UV: ultraviolet
VT: visual testing